Economic and Environmental Perspectives of Hydrogen Infrastructure Deployment Options

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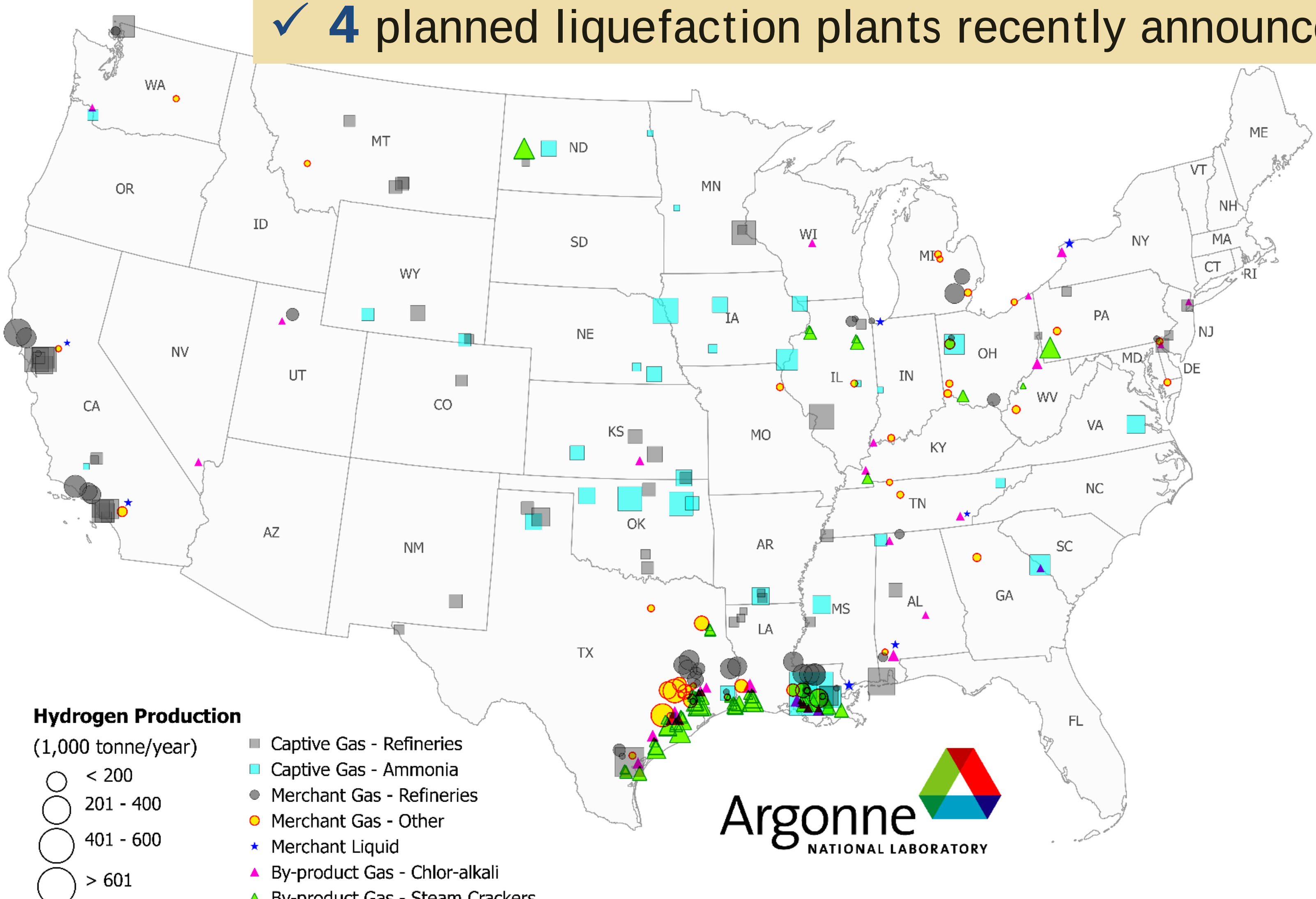
Today, more than 10M metric tons of hydrogen are produced in the U.S. annually

1600 mi. of H_2 pipeline; **10** Liquefaction plants in North America

✓ **4** planned liquefaction plants recently announced



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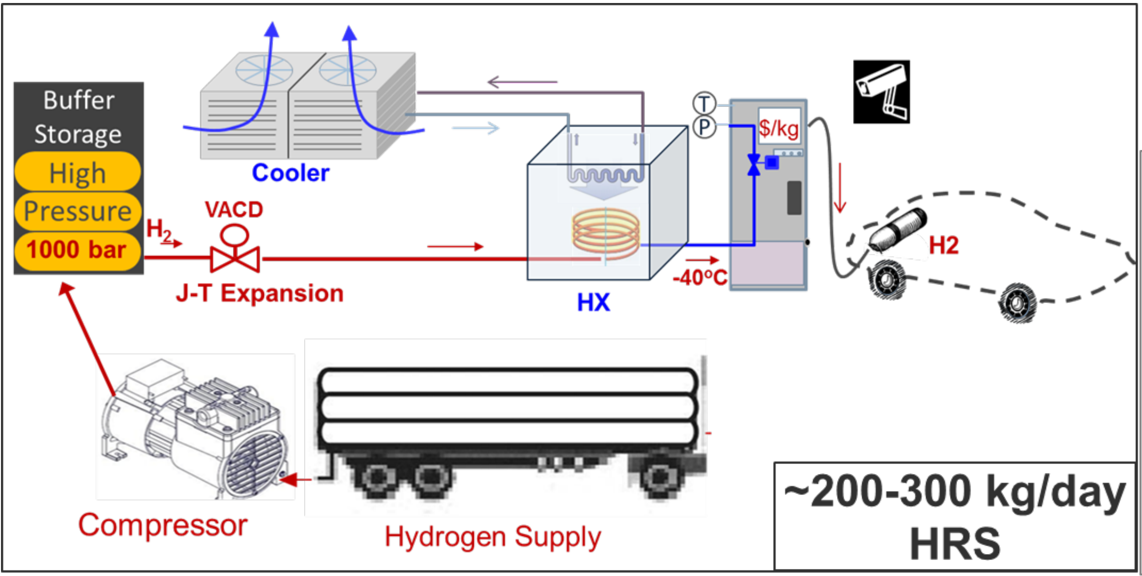
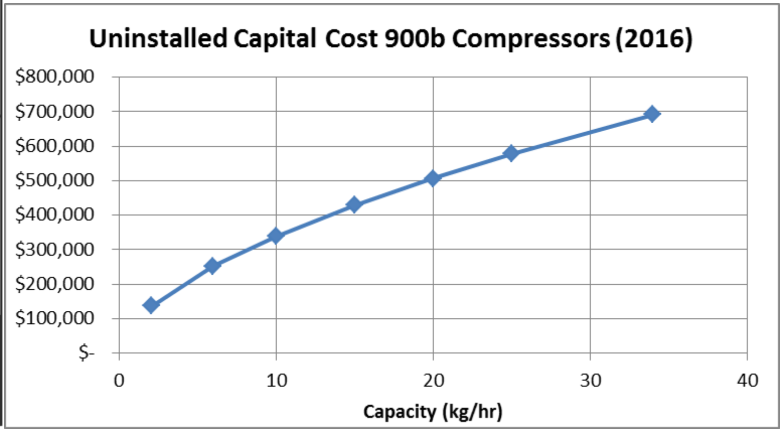
Today, hydrogen cost at the dispenser in CA is \$13-\$16/kg





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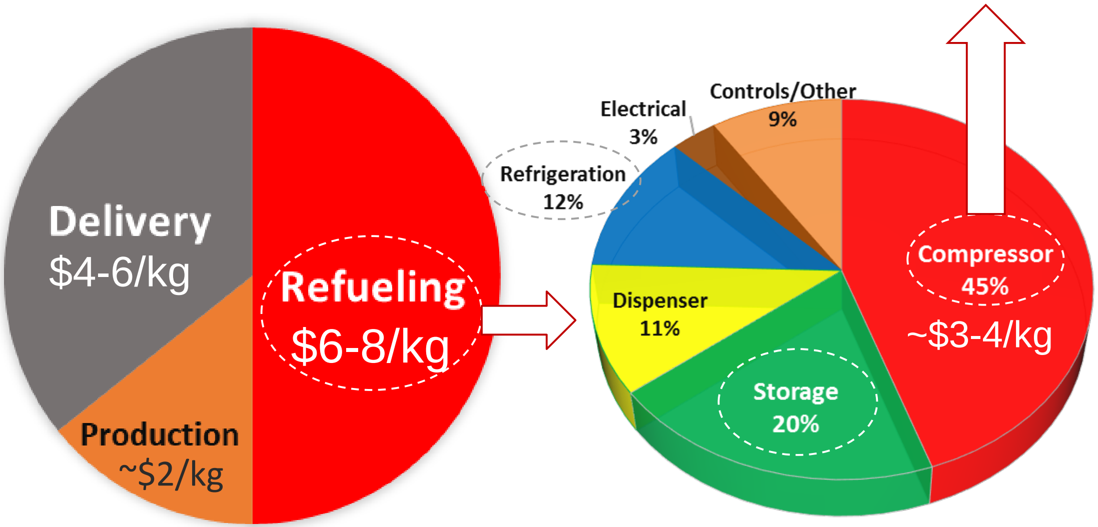
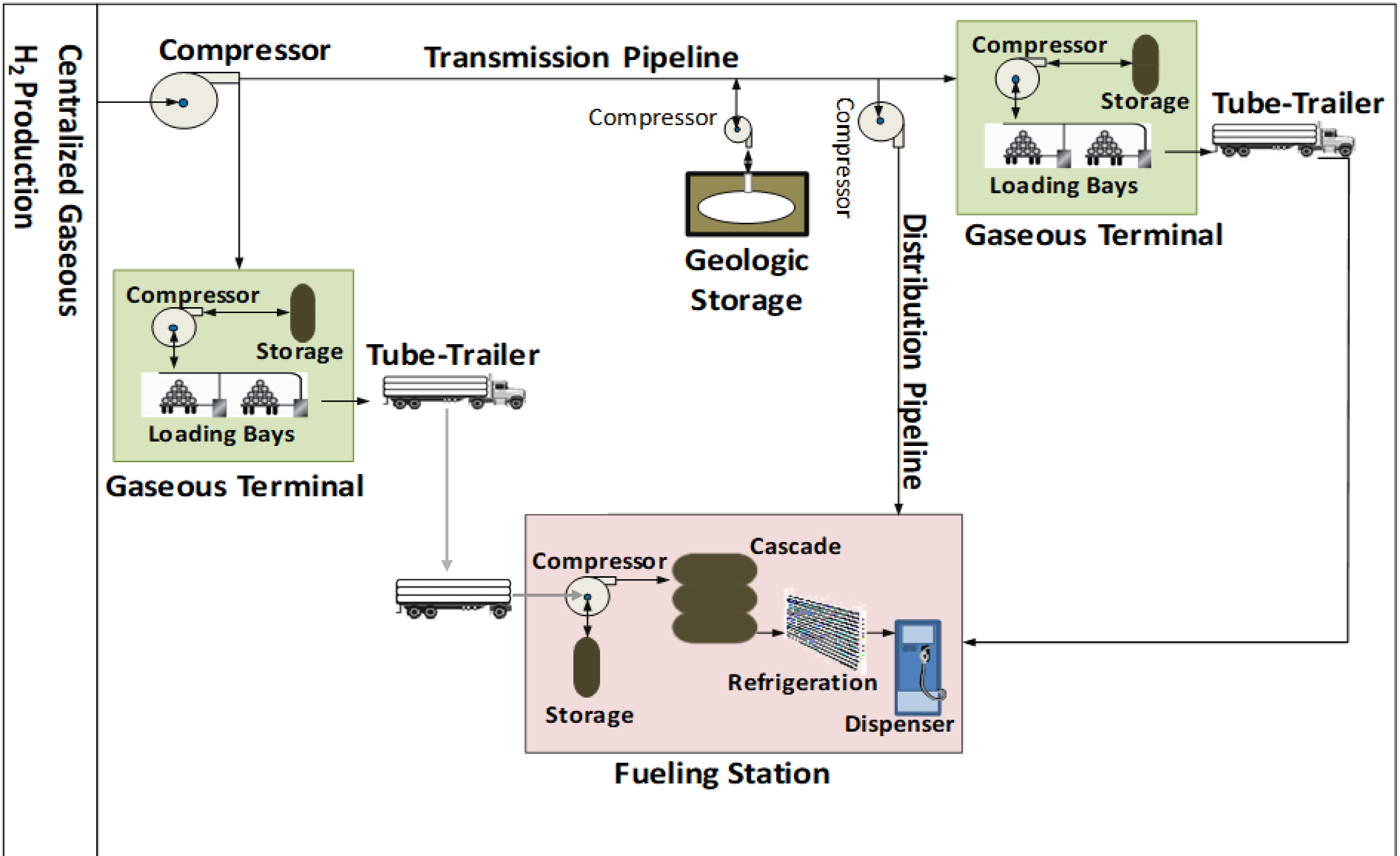
Bulk of H_2 cost is in delivery and refueling



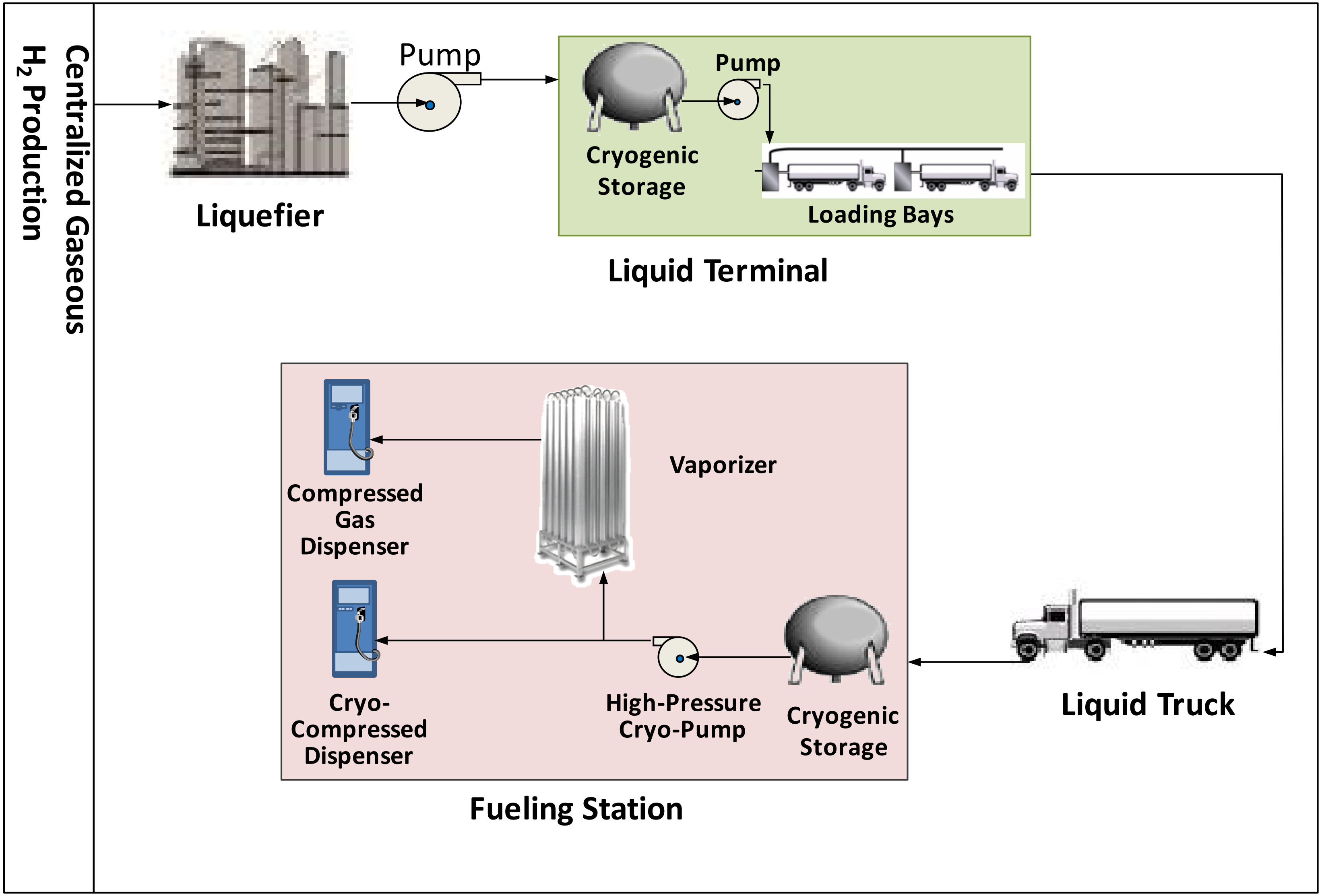
Tecno-Economic Analysis (TEA) suite of models

https://hdsam.es.anl.gov/

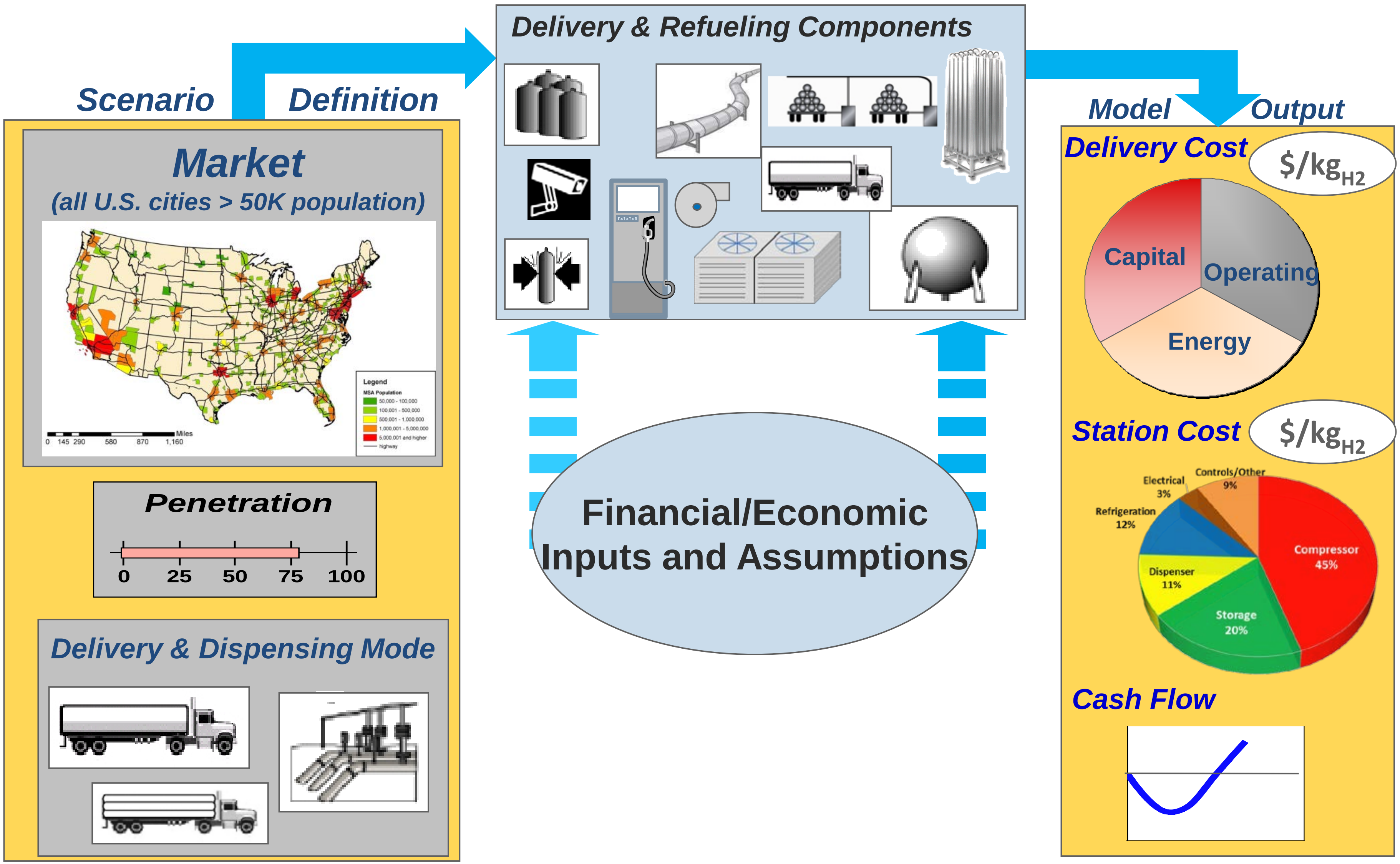
Infrastructure of Gaseous Hydrogen Delivery



Infrastructure of Liquid Hydrogen Delivery



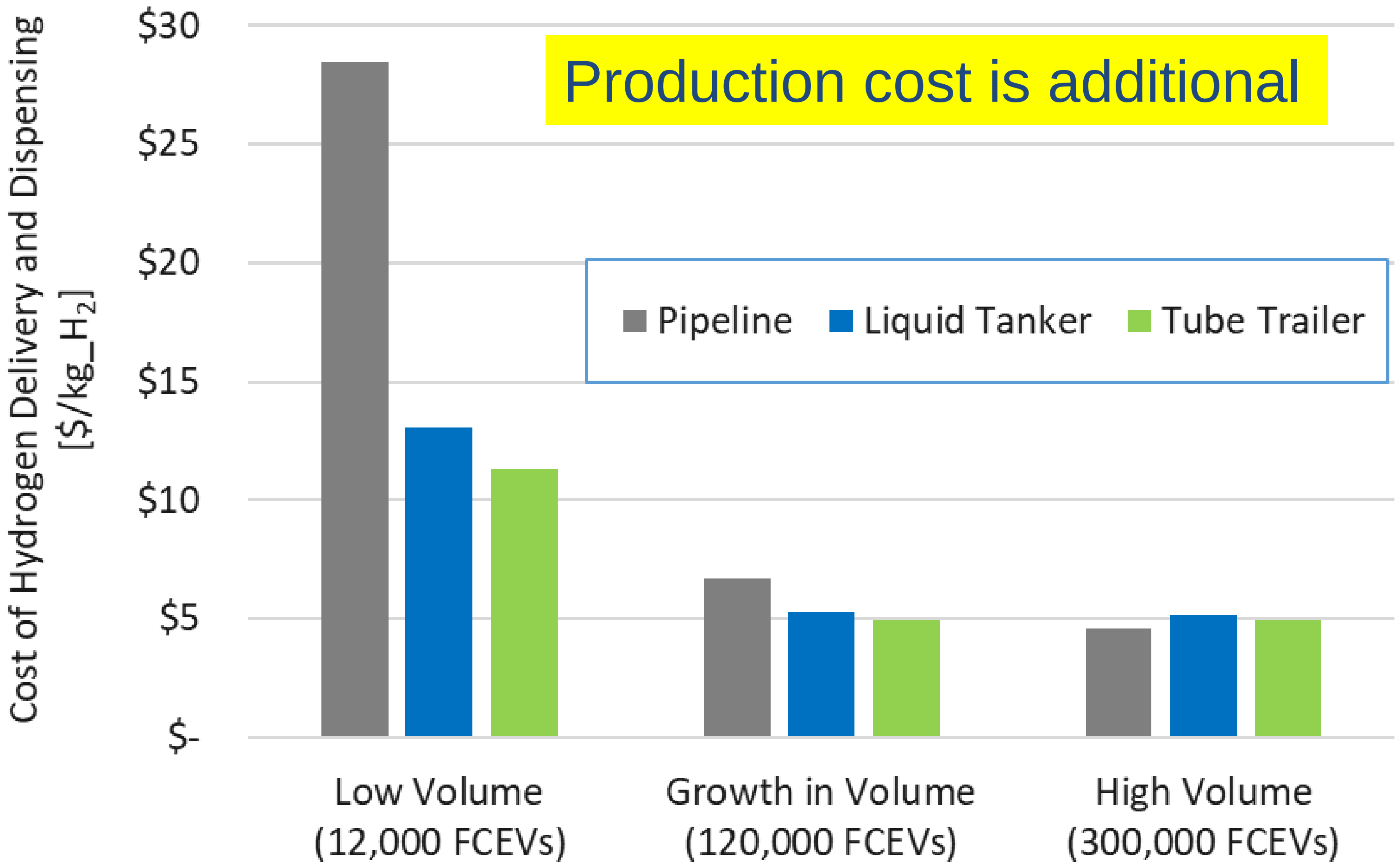
Hydrogen Delivery Scenario Analysis Model (HDSAM)



https://hdsam.es.anl.gov/index.php?content=hdsam

Costs of New Delivery & Dispensing for LDVs

Assuming current technology



- ➢ Trucking is lowest cost option with small market demand (near-term)
- ➢ Pipeline is lowest cost option with large market demand (long-term)

Hydrogen Refueling Station Models

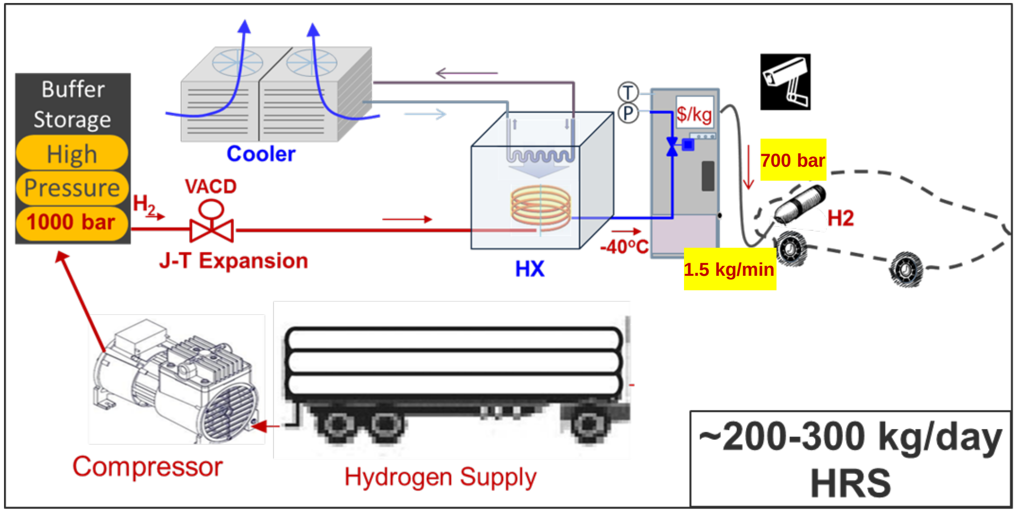
Evaluate impacts of key market, technical, and economic parameters on refueling cost [$/kg$_{H2}$] of light-duty and heavy-duty fuel cell vehicles

HRSAM

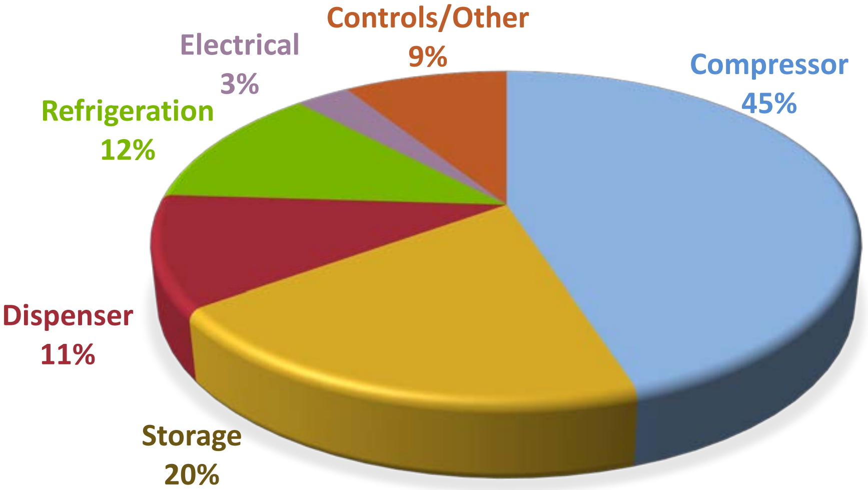
HDRSAM

Available at: http://hdsam.es.anl.gov/

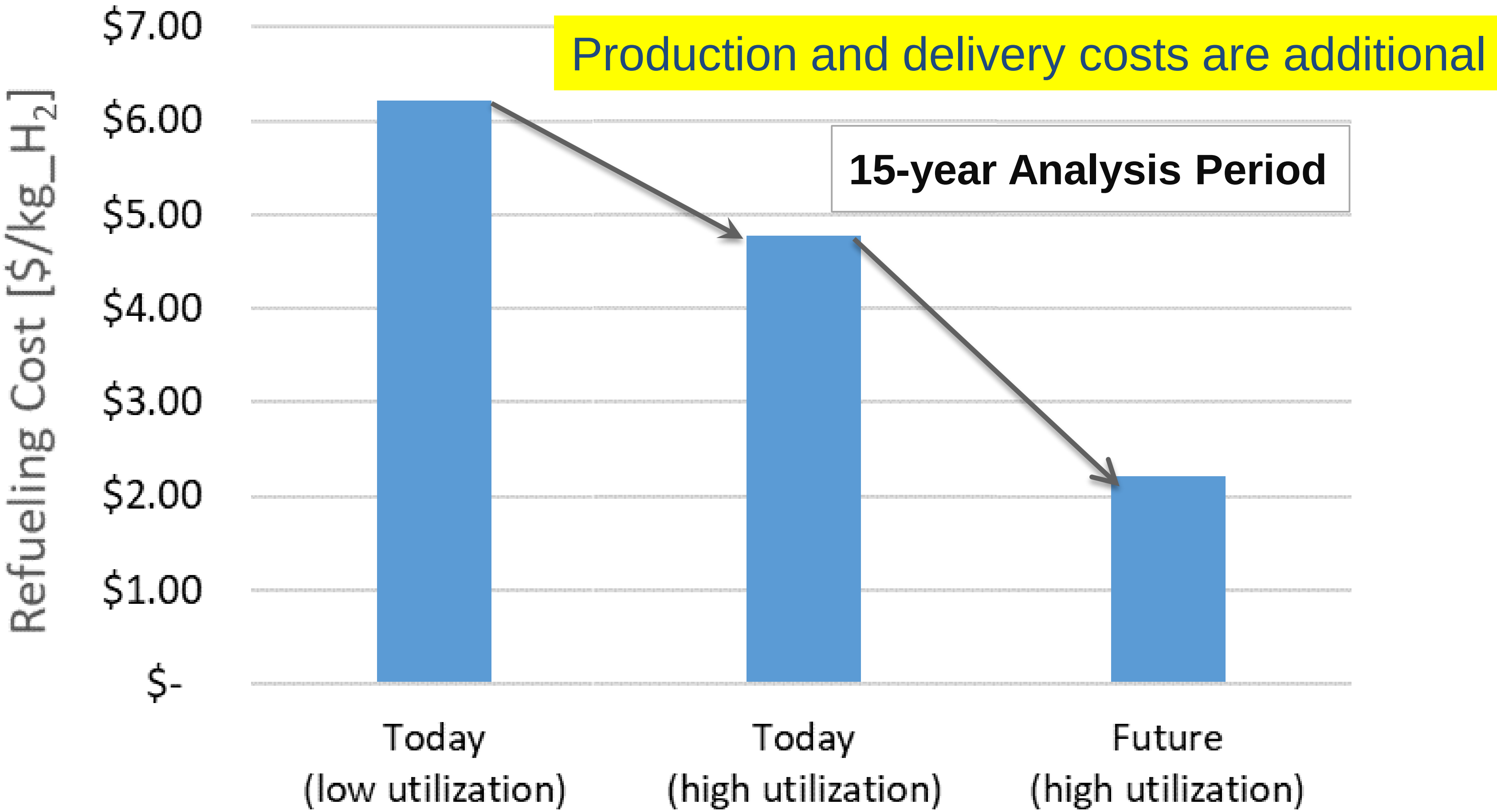
Cost Drivers of Hydrogen Fueling



Capital Costs of Hydrogen Fueling Stations (Simulated, $1.5-$2M)



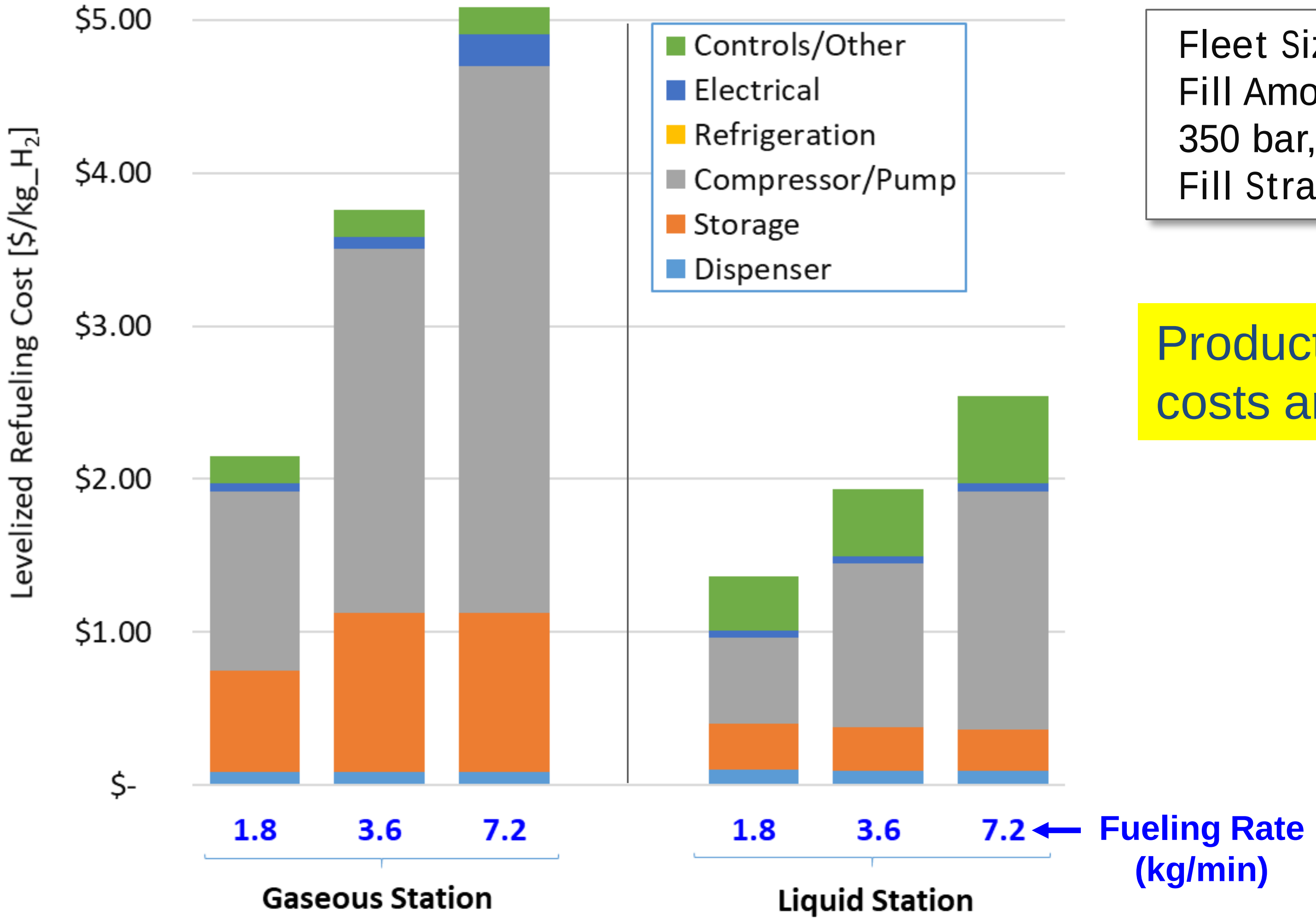
Impact of station utilization and capacity on refueling station cost for FC LDVs



Today (low volume)
Early market (12,000 FCEVs)
300 kg/day station

Future (R&D and high volume)
Mature market (120,000 FCEVs)
1000 kg/day station

Impact of fueling rate on FC HDV refueling cost

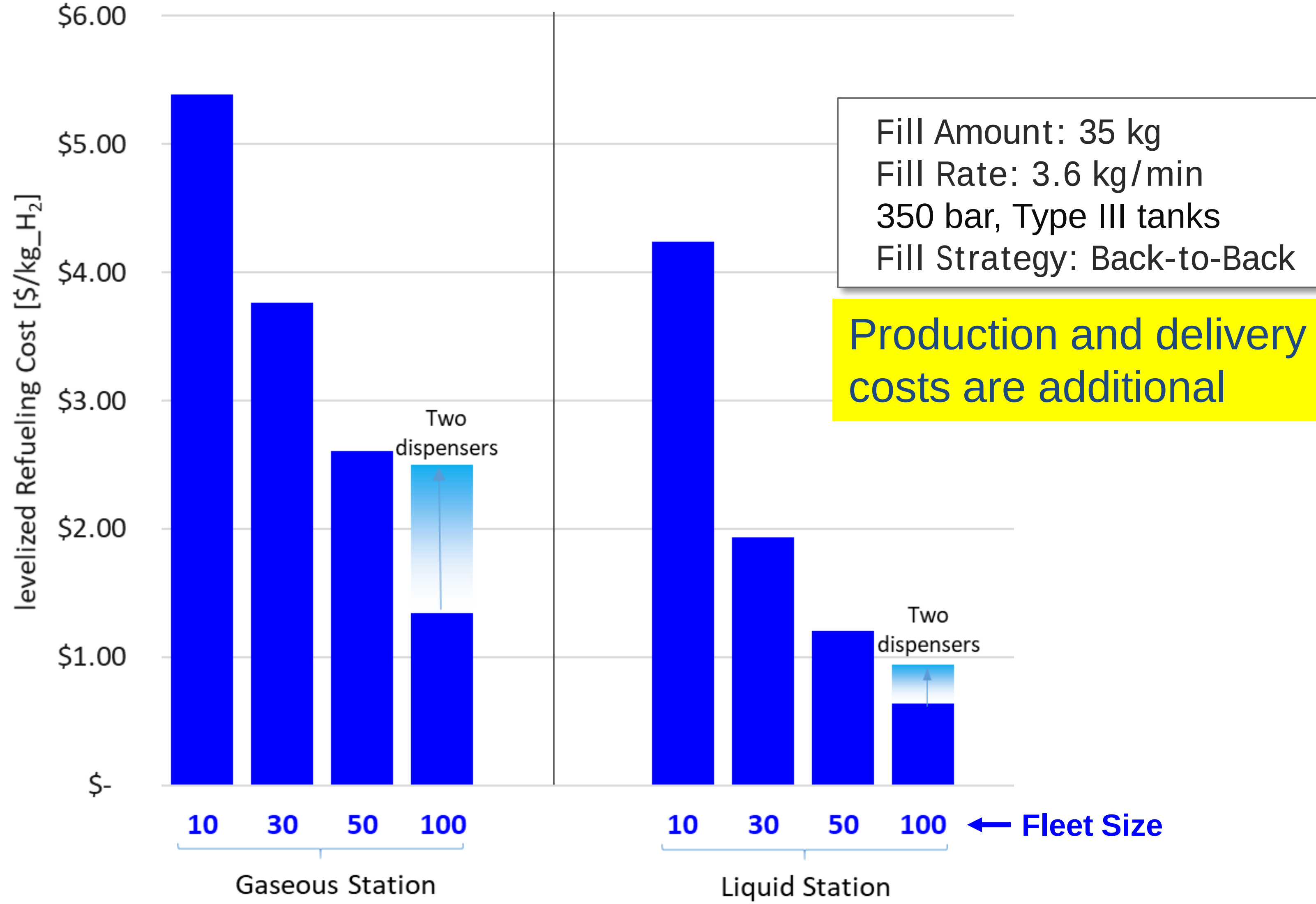


Fleet Size: 30 buses
Fill Amount: 35 kg
350 bar, Type III tanks
Fill Strategy: Back-to-Back

Production and delivery costs are additional

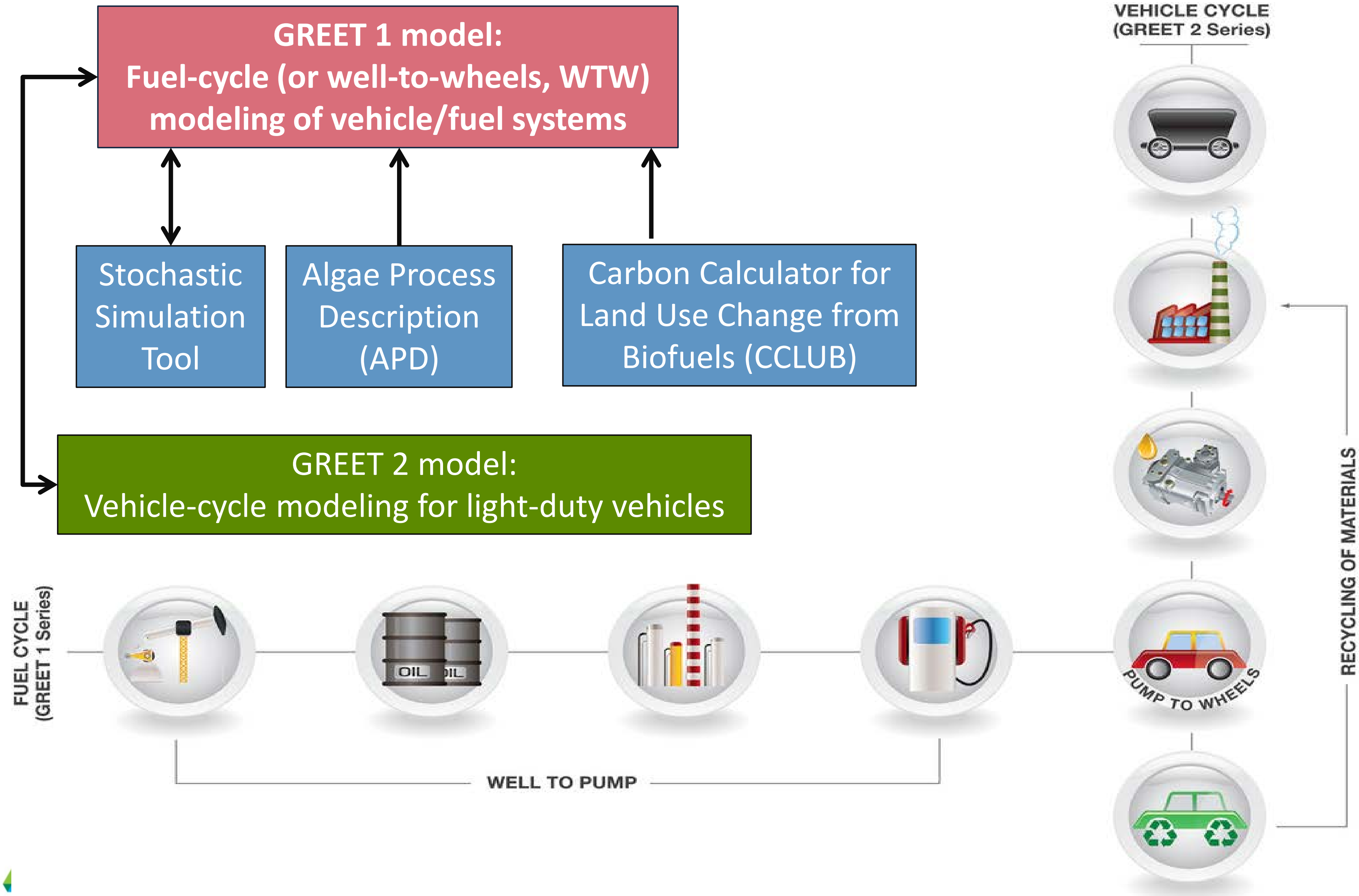
- Faster fills require higher capacity equipment and result in higher cost
- Liquid stations can handle faster fills with less cost increase

Impact of HDV fleet size (demand) on refueling cost

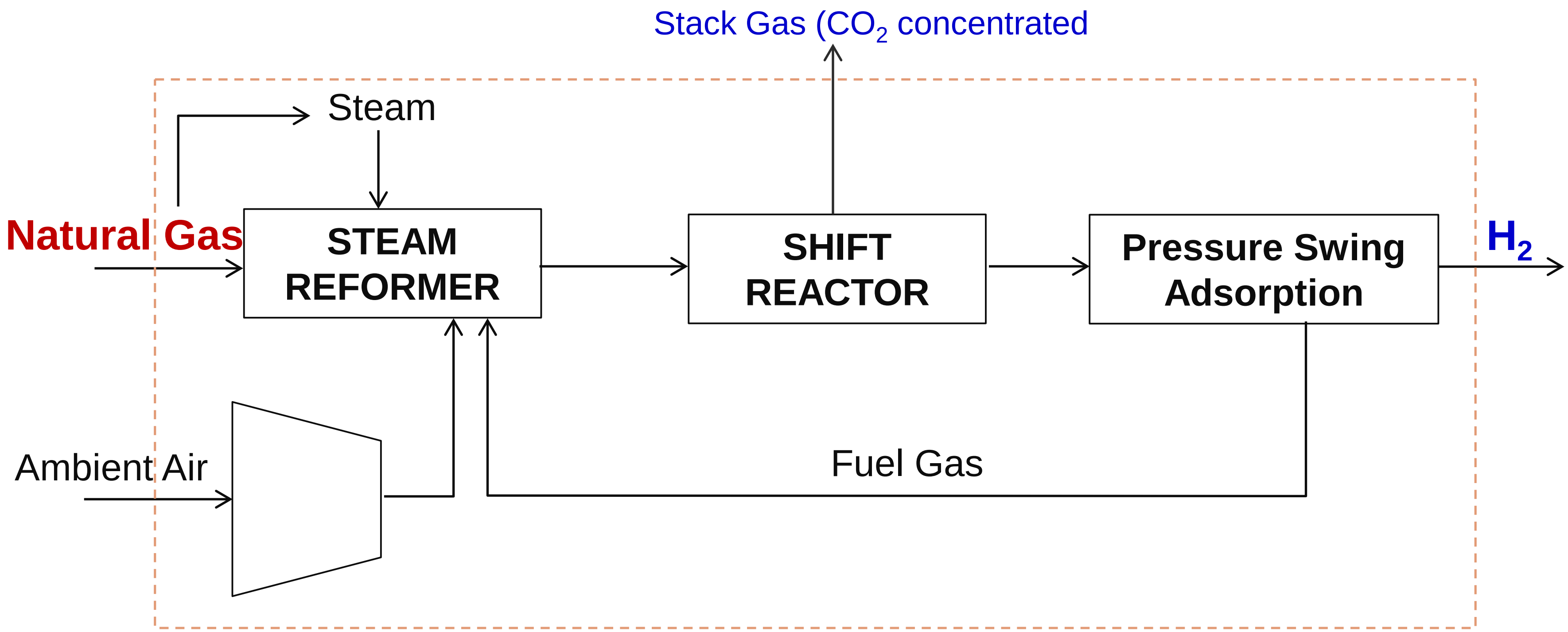


- Fleet sizes have a strong impact: cost can drop to ~$1/kg$_{H2}$ with large fleet size
- Liquid station, in general, provides a lower refueling cost option

The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model



Hydrogen production today is mainly from SMR, but other low-carbon pathways exist today



At 72% NG to H_2 energy efficiency (LHV-basis)

→ Well-to-plant gate GHG emissions= 11 $kg_{CO_{2e}}/kg_{H_2}$

Note: Gasoline (E10) WTW GHG emissions also = 11 $kg_{CO_{2e}}$/GGE

Energy Penalty and GHG Emissions are Critical for Environmental Impacts of Liquefaction

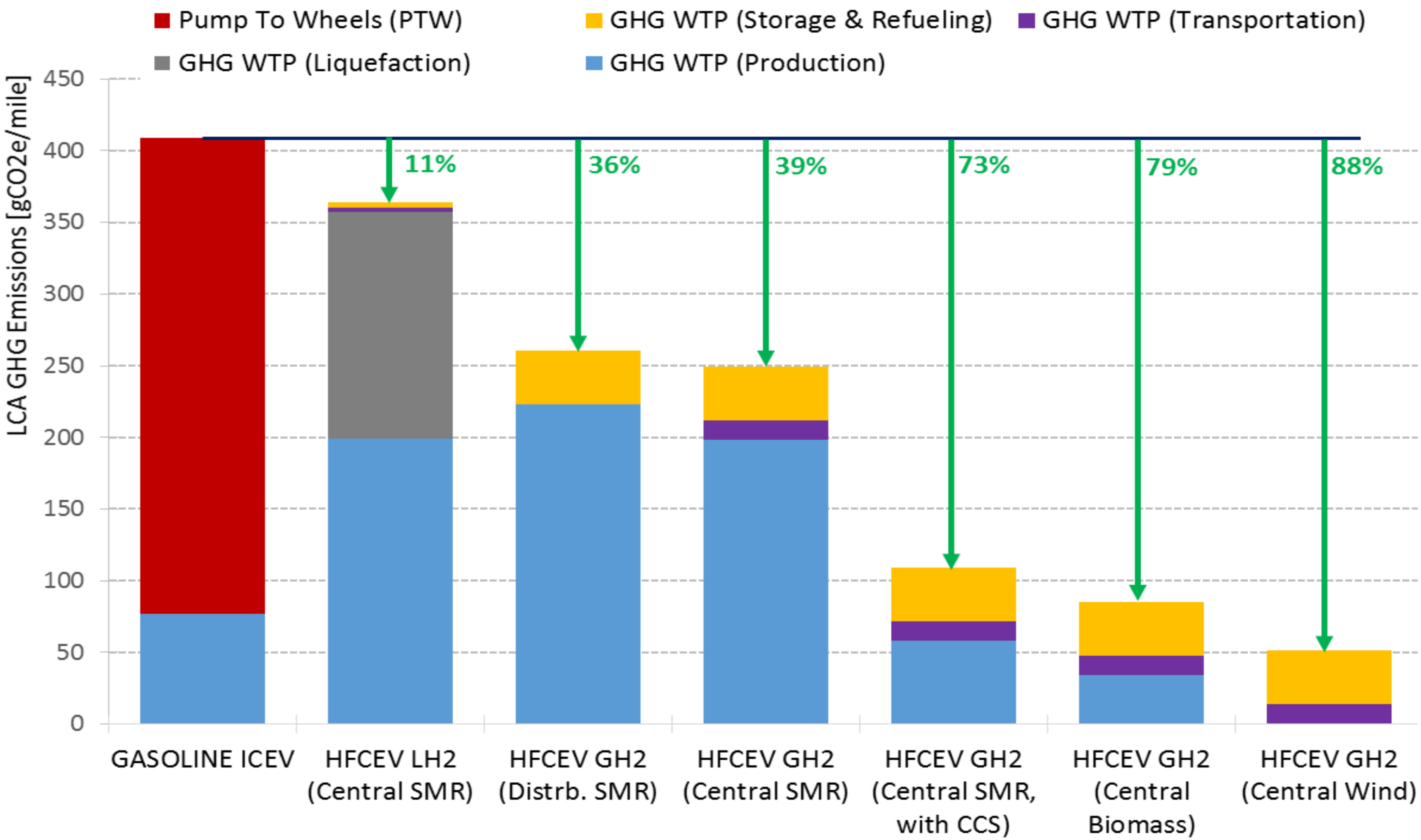
Region	Liquefaction Capacity (MT/day)
California	30
Louisiana	70
Indiana	30
New York	40
Alabama	30
Ontario	30
Quebec	27
Tennessee	6
Total	263

→ Liquefaction GHG emissions*= 0-7 $kg_{CO_{2e}}/kg_{H_2}$

Four additional H_2 liquefaction plants have been recently announced to serve the growing market

*12 $kWhe/kg_{H2}$

Renewable sources are key for sustainable H_2 production



Assuming 26 mpg for gasoline ICEV and 55 mpgge for H_2 FCEV

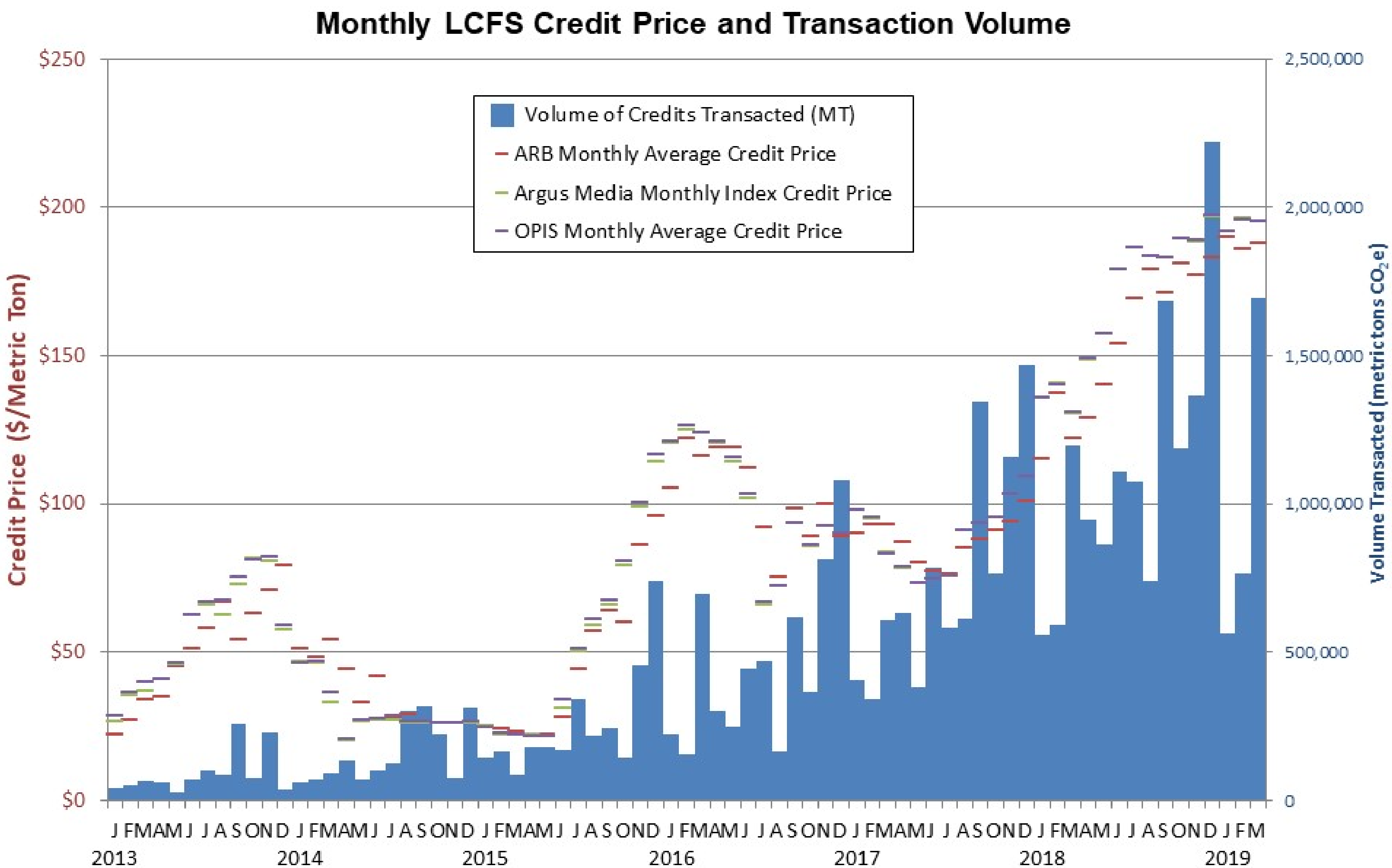
Renewable H_2 roll out with public support is needed to overcome challenges of early markets

Market Phase	Public Support?	Profitable?	Technology Reliable?	Sustainable?
[1] Demonstration	Yes	No	No	No
[2] Early/ Precommercial	Yes	Yes	No	Pseudo Sustainable*
[3] Commercial	No	Yes	Yes	Self Sustainable

* i.e., with public support

California LCFS can also generate credits for H_2 production and delivery pathways

- Hydrogen to be a mandatory reporting fuel
- LCFS credits recently trading near $200/MT
  - Can reduce H_2 cost by $2-$6/kg_{H2}



1 kg_{H2} = 1 GGE

source: http://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

Acknowledgment

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